Supplementary material to the article

Assessing the need for critical minerals to shift the German energy system towards a high proportion of renewables

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ad 3.4: Choosing a plausible range of long-term technology deployment

For this work, energy scenario studies are taken into account if

- they were released between early 2009 and late 2012
- they provide sufficient quantitative information about the German electricity system in the year 2050 and
- their scenarios either (roughly) achieve or overachieve the German government's 80% target for the share of renewables in covering electricity demand in 2050.

Table 1 provides an overview of the eight scenario studies taken into account. All scenarios achieve electricity sector CO_2 emission reductions of more than 90% compared to 1990 levels by 2050, allowing the government's target of reducing *all* GHG emissions by at least 80% by 2050 to be realised (depending on emission reductions in other energy and non-energy sectors).

Table 1 Overview of scenario studies and scenarios taken into account to derive future deployment of renewable energy and storage technologies

Name of the study	Commissioning institution	Scenario(s) chosen
100% Renewables for Electricity and Heat in Germany (Fraunhofer ISE 2012)	Fraunhofer Institute for Solar Energy Systems	REMax
Long term scenarios and strategies for the deployment of renewable energies in Germany under the consideration of European and global developments (BMU 2012)	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety	Scenario 2011 A
Pathways towards a 100% renewable electricity system (SRU 2011)	German Advisory Council on the Environment	Scenario 2.1.a Scenario 2.1.b
Scenarios for an Energy Policy Concept of the German Government (BMWi/BMU 2010)	Federal Ministry for Economic Affairs and Energy and Federal Ministry for the Environment, Nature Conservation and Nuclear Safety	Scenario I B
Energy Concept 2050 for Germany with a European and Global Perspective (FVEE 2010)	Renewable Energy Research Association	100% RE
Energy target 2050: 100% renewable electricity supply (UBA 2010)	Federal Environment Agency	Regions Network
Climate Protection: Plan B 2050 – An Energy Concept for Germany (Greenpeace 2009)	Greenpeace	Plan B
Blueprint Germany – A strategy for a climate safe 2050 (WWF 2009)	WWF	Innovation w/o CCS Innovation with CCS

Ad section 3.5: Deriving the cumulative demand of critical minerals by 2050

Cumulative critical mineral demand for photovoltaics deployment

Table 2 Estimated cumulative critical mineral demand for *photovoltaics* deployment in Germany between 2011 and 2050

Element	Deployment level	Roadmap	
		"Continuity"	"Thin film renaissance"
		t	t
Indium	low	26	189
	medium	51	353
	high	73	516
	very high	130	949
Gallium	low	2	22
	medium	5	40
	high	7	61
	very high	13	121
Selenium	low	13	119
	medium	26	213
	high	39	328
	very high	69	647
Cadmium	low	11	14
	medium	28	36
	high	45	55
	very high	62	80
Tellur	low	8	8
	medium	23	23
	high	37	37
	very high	49	49

Cumulative critical mineral demand for onshore and offshore wind deployment

Table 3 Estimated cumulative critical mineral demand for *onshore wind* deployment in Germany between 2011 and 2050

Element	Deployment level	Roadmap		
		"Continuity"	"Upscaling"	"HTS"
		t	t	t
Neodym	low	377	2,920	2,437
	medium	498	3,739	3,119
	high	674	5,286	4,376
	very high	1,817	15,499	12,625
Dysprosium	low	29	226	189
	medium	38	284	240
	high	52	402	337
	very high	142	1,196	989
Yttrium	low			1.0
	medium			1.2
	high			1.8
	very high			5.7

HTS = high temperature super conducting

Table 4 Estimated cumulative critical mineral demand for *offshore wind* deployment in Germany between 2011 and 2050

Element	Deployment level	Roadmap		
		"Continuity"	"Upscaling"	"HTS"
		t	t	t
Neodym	low	732	1,520	1,204
	medium	1,340	2,834	2,214
	high	2,579	5,559	4,312
	very high	2,823	6,101	4,723
Dysprosium	low	48	95	76
	medium	90	191	146
	high	159	347	262
	very high	174	379	286
Yttrium	low			0.6
	medium			1.1
	high			2.2
	very high			2.4

HTS = high temperature super conducting

Table 5 Estimated cumulative critical mineral demand for *onshore and offshore wind* deployment in Germany between 2011 and 2050

Element	Deployment level	Roadmap		
		"Continuity"	**"Upscaling"**	**"HTS"**
		t	t	t
Neodym	low	1,109	4,440	3,641
	medium	1,838	6,573	5,333
	high	3,253	10,845	8,688
	very high	4,640	21,600	17,348
Dysprosium	low	77	321	265
	medium	128	475	386
	high	211	749	599
	very high	316	1,575	1,275
Yttrium	low			1.6
	medium			2.3
	high			4
	very high			8.1

HTS = high temperature super conducting